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Search for 1.809 MeV Emission of ^{26}Al from nearby Supernova Remnants using COMPTEL

Jürgen Knödlseder[1,2], Uwe Oberlack[2], Roland Diehl[2], Wan Chen[3,4], and Neil Gehrels[3]

[1]Centre d'Etude Spatiale des Rayonnements, CNRS/UPS, BP 4346, 31029 Toulouse Cedex, France
[2]Max Planck Institut für extraterrestrische Physik, Postfach 1603, 85740 Garching, Germany
[3]NASA/Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, USA
[4]Universities Space Research Association

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Abstract. We report the negative results of our searches in COMPTEL data for 1.809 MeV gamma-ray line emission from four localized regions which contain nearby supernova remnants (SNRs). The upper flux limits (2σ) are found to be in the range of 1.4×10^{-5} to 2.4×10^{-5} photons s^{-1} cm^{-2}. These upper limits do not severely constrain the theoretical ^{26}Al yields from individual core collapse supernovae due to large uncertainties in the SNR distances and the nature of the progenitor stars.

Key words: gamma-rays: observations – nucleosynthesis – supernovae – ISM: supernova remnants

1. Introduction

One of the outstanding achievements of the Compton Imaging Telescope (COMPTEL) aboard the *Compton Gamma Ray Observatory* has been the first sky map in the light of the 1.809 MeV γ-ray line which is attributed to radioactive decay of ^{26}Al ($\tau = 1.04 \times 10^6$ yr). The observed emission is clearly of Galactic origin since it is concentrated on the Galactic plane. Its distribution along the plane is strikingly lumpy with extended emission features and 'hot-spots' (Diehl et al. 1995a). One of these features, situated in the Vela region, is of particular interest (Diehl et al. 1995b). A recent survey of candidate ^{26}Al sources (core collapse supernovae (SNe), Wolf-Rayet (WR) stars, asymptotic giant-branch (AGB) stars, and O-Ne-Mg novae) in this region of the sky by Oberlack et al. (1994) identified the Vela supernova remnant (SNR) as most likely source of the emission if its progenitor star was massive (~ 35 M$_\odot$) and its distance is ≤ 350 pc. The distance constraint is in line with recent X-ray based distance estimates of 350, 400-600, and 125-160 pc (Aschenbach 1993, Aschenbach et al. 1995, Becker 1995), respectively, all pointing towards distances below the canonical 500 pc. These findings raise the question if there are other SNRs detectable by COMPTEL as ^{26}Al sources. From the 1.8 MeV γ-ray line sensitivity of $\sim 10^{-5}$ photons cm^{-2} s^{-1} (for an observation of 10^6 seconds) and an optimistic ^{26}Al supernova yield of 3×10^{-4} M$_\odot$ for type II SNe (Hoffman et al. 1995) we estimate that SNe could be detectable by COMPTEL up to distances of $\sim$ 600 pc. In this paper we report on our attempt to identify probable candidate SNRs and on the search for their 1.809 MeV γ-ray line emission.

Send offprint requests to: Jürgen Knödlseder (Toulouse)

2. Supernova Remnants as ^{26}Al source tracer

2.1. SNR types

While SNRs are assumed to be produced by all types of SNe, only core collapse events (type II and Ib) are expected to release significant amounts of ^{26}Al (Leising 1994). Unfortunately, there is no certain, direct way to determine which of the Galactic SNRs are associated with core collapse events. For the historical SNe, knowledge of the light curve sheds some light on their type, but the identification is not unambigous (Doggett & Branch 1985). The presence of a neutron star within a SNR would identify it as core collapse remnant, but there are only 10 known Galactic SNR-pulsar associations (Caraveo 1993). All of them except the Vela SNR, however, are at distances greater than 1.8 kpc, much too far to be detectable by COMPTEL (see above). Recently, evidence is growing that oxygen-rich and plerionic-composite SNRs may come from type Ib and type II SNe respectively (van den Bergh 1988, Weiler & Sramek 1988, Sutherland & Dopita 1995). However, most of the Galactic SNRs don't fall in these classes.

2.2. SNR distances

The key element in our candidate source selection is the distance of the remnant. Of the 194 SNRs known in our Galaxy (Green 1995), only 23 have good or reasonable distance estimates (Green 1991). From those, only the Vela SNR is close enough to be detectable by COMPTEL. For the other SNRs, only rough or no distance estimates are available which makes the direct determination of the nearest ^{26}Al source candidates unfeasible. Therefore, we used the empirical radio surface brightness - diameter relation (Σ-D relation) to identify the closest SNRs (e.g. Berkhuijsen 1986). Green (1984, 1991) pointed out that the Σ-D relation cannot provide accurate distances to individual SNRs, but Berkhuijsen (1986) showed that it sets reliable upper distance limits: using $\Sigma \propto D^{-3.5}$ (Berkhuijsen 1986), none from 23 SNRs are found in the region where the distance measurement contradicts those upper limits (see Fig. 1, grey-shaded area).

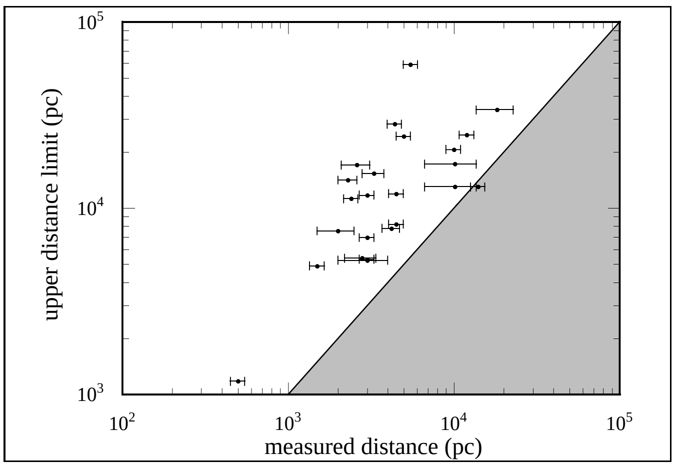

Fig. 1. Upper distance limits derived by Berkhuijsen's (1986) Σ-D relation for 23 SNRs with good or reasonable distance measurements. The grey-shaded area marks the range where the Σ-D relation contradicts the measurements.

2.3. Candidates for SNR search

Using Berkhuijsen's (1986) Σ-D relation as distance indicator, we selected four SNRs as possible candidates for nearby ^{26}Al sources: the Cygnus Loop, the Monoceros Nebula, the Lupus Loop and HB 21. Selecting the SNRs with the lowest distance limits obviously chooses nearby objects, but not necessarily all of them. There could be nearby SNRs which are not extended or not very powerful and therefore have large distance limits. None of the selected remnants is in Green's (1984, 1991) lists of good or reasonable distance determinations, but crude estimates are available for all of them. We compiled the relevant properties of the four candidates in Table 1 along with those of the Vela SNR.

The Cygnus Loop and HB 21 were probably created by core collapse events. X-ray observations with EINSTEIN provide evidence for cavities devoided of clouds prior to the explosions, probably created by the stellar winds of the progenitor stars (Charles et al. 1985, Leahy 1987). Since strong stellar winds are only expected for massive stars, the SNe must have been of type II or Ib.

Also the Monoceros Nebula was probably created by a core collapse event. Odegard (1986) summarizes observational evidence which indicates that the Monoceros Nebula is associated with the Mon OB2 stellar association and the Rosette Nebula. Since low-mass stars are generally not very evolved in OB associations, the occurence of type Ia SNe is rather improbable. Hence if a SNR is located in an OB associations it is likely that it arose from the explosion of a massive star.

We found no indication of SN type for the Lupus Loop in the literature. However, the (fairly uncertain) distance estimate of 1.2 kpc (Leahy et al. 1991) and its high Galactic latitude of b=15.97° places it 330 pc above the Galactic plane. This height is more typical for the old stellar population than for young massive objects which would favour the relation of the SNR to a type Ia event. Nevertheless, we included this object in our 1.8 MeV emission search.

3. Observations and Data Analysis

We used COMPTEL data collected between May 1991 and October 1994 for the 1.8 MeV γ-ray line search. In summary, $\sim$ 100 different pointings (observation periods) were combined, yielding a 1.8 MeV γ-ray line sensitivity of $\sim$ 1.5×10^{-5} photons cm^{-2} s^{-1} (2σ) for all candidate sources. Measured γ-ray photons with energies between 1.7-1.9 MeV were binned in a three-dimensional data-space, spanned by the scatter direction (χ, ψ) (defined by the photon's interaction locations in the two detector layers of the instrument), and the Compton scatter angle $\bar{\varphi}$ (defined by the energy deposits in these two layers; see Schönfelder et al. (1993) for a detailed description of the instrument). For each SNR search, a data-space enclosing $\pm 50°$ around the SNR position was employed. The data-space distribution of instrumental background was derived from measurements at adjacent energy bands (Knödlseder et al. 1996). The search for 1.8 MeV emission was carried out by convolving models of the SNRs into the data-space which were fitted along with the background model to the data. The maximum-likelihood technique (de Boer et al. 1992) was applied to determine flux, flux error, and detection significance for all models. Upper limits of 1.8 MeV emission were determined by variation of the SNR source flux to obtain a likelihood-ratio corresponding to 2σ limits above the best-fit (or above zero flux in cases where the best fit gave a negative source flux).

Table 1. Properties of nearby supernova remnants (Green 1984, 1991). The upper distance limits were derived using the Σ-D relation $\Sigma_{1\mathrm{GHz}} = 2.51 \times 10^{-14}$ D$^{-3.5}$ W Hz^{-1} m^{-2} sr^{-1} of Berkhuijsen (1986).

Name	l (deg)	b (deg)	$F_{1\mathrm{GHz}}$ (Jy)	$\Sigma_{1\mathrm{GHz}}$ (W Hz^{-1} m^{-2} sr^{-1})	Radio Size D (arcmin)	Distance (kpc)	Upper distance limit (kpc)
Vela SNR	263.9	-3.3	1750	4.1×10^{-21}	255	< 0.5	1.2
Cygnus Loop	74.01	-8.56	210	6.0×10^{-22}	195	0.77[a]	2.4
HB 21	88.86	4.80	220	2.3×10^{-21}	105	0.8[b]	3.1
Mon Nebula	204.96	0.45	160	5.0×10^{-22}	220	1.6[c]	2.5
Lupus Loop	329.67	15.97	350	1.6×10^{-21}	180	1.2[d]	2.2

[a] from a combination of optical proper motion and radial velocity observations (Minkowski 1958).
[b] from a possible association with Cyg OB7 (Tatematsu et al. 1990).
[c] from a possible association with Mon OB2 and the Rosette nebula (Odegard 1986).
[d] from a model-fit to X-ray data, assuming a SN explosion energy of $E_0 = 10^{51}$ erg (Leahy et al. 1991).

4. Results

Since it is not clear how the ^{26}Al is distributed within the SNRs, we tested two extreme hypotheses for each candidate: (1) all ^{26}Al is confined to the center of the remnant (point source hypothesis), and (2) the ^{26}Al is distributed homogeneous over the SNR (extended source hypothesis). However, we don't expect large differences in the results from both hypotheses because the sizes of the SNRs are of the same order as COMPTEL's angular resolution of 3.8° (FWHM).

We did not detect significant 1.8 MeV emission from any of the four SNR positions. The upper flux limits (2σ) for all remnants are listed in Table 2 for the point source and extended source hypotheses. The last column quotes the assumed diameters for the extended source hypotheses. In general, the extended source models yield somewhat higher limits than the point source models, particularly for the Monoceros Nebula which lies in the vincinity of an insignificant 1.8 MeV emission feature. The highest limits for both the point source and the extended source hypotheses were obtained for HB 21. Formally, HB 21 yields a small signal, but since this SNR is embedded in an extended 1.8 MeV emission feature along the direction of Cygnus, the signal can possibly be attributed to the local spiral arm (for a discussion of 1.8 MeV emission from the Cygnus region see del Rio et al. (1994)). We found no evidence for 1.8 MeV emission from HB 21 on top of the extended emission.

Table 2. COMPTEL upper limits (2σ) for 1.8 MeV emission from four nearby SNRs.

Name	Point source upper limit	Extended source upper limit	Extended source diameter
	(photons cm^{-2} s^{-1})	(photons cm^{-2} s^{-1})	(deg)
Cygnus Loop	1.5×10^{-5}	1.5×10^{-5}	4.0
HB 21	2.3×10^{-5}	2.4×10^{-5}	2.0
Mon Nebula	1.6×10^{-5}	2.2×10^{-5}	4.0
Lupus Loop	1.4×10^{-5}	1.6×10^{-5}	3.0

5. Discussion

The two main parameters which affect the expected 1.8 MeV flux from a SNR are its distance and the amount of ^{26}Al which was ejected during the SN explosion. For type II events, recent nucleosynthesis calculations are available covering initial progenitor star masses from 11-40 $M_\odot$ (Weaver & Woosley 1993; Hoffman et al. 1995). For type Ib events no consistent stellar evolution calculations including ^{26}Al nucleosynthesis were followed up to the final SN explosion yet, but Woosley et al. (1993) estimate 'a few times 10^{-5} $M_\odot$ of ^{26}Al'. However, if type Ib SNe come from explosions of single WR stars (Woosley et al. 1995), substantial amounts of the ^{26}Al which was ejected during the WR phase (Langer et al. 1995) and which dominates the explosion yield should still be alive, since the time between the onset of the WR phase and the death of the star is shorter than the ^{26}Al lifetime.

The wide range of possible ^{26}Al yields for different SN models does not allow to put severe constraints on the SNR parameters (see Fig. 2). Assuming that the observed SNRs originate from type II events, the upper flux limits correspond to minimum remnant distances between 90 and 500 pc, depending on the initial mass of the progenitor star. These lower limits are consistent with the distance estimates for the four SNRs which range from 770 pc for the Cygnus Loop to 1.6 kpc for the Monoceros Nebula. For type Ib SN the lower distance limits are somewhat higher, reaching up to 900 pc for an initial progenitor star mass of 140 $M_\odot$. Thus, if the SNR distance estimates are

reliable, our 1.8 MeV upper limits exclude such extremly massive progenitor stars for the Cygnus Loop and HB21.

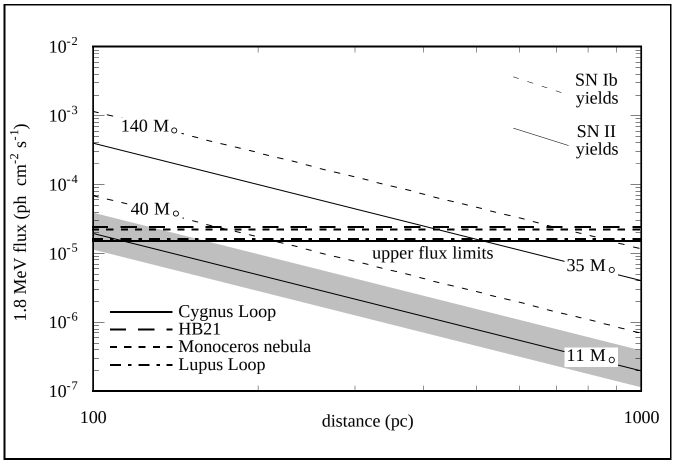

Fig. 2. Expected SNR 1.809 MeV flux versus remnant distance for type II (Weaver & Woosley 1993; Hoffman et al. 1995) and type Ib SNe (Langer et al. 1995). The grey area indicates the range of type II yields from variation of the physical parameters of models for 20 M$_\odot$ progenitors. The COMPTEL upper flux limits are drawn as horizontal lines. Models which lie above these lines are excluded by the measurement.

6. Conclusions

Observations of four nearby supernova remnants with COMPTEL do not provide evidence for 1.8 MeV line emission from radioactive decay of ^{26}Al. We obtain upper flux limits for the Cygnus Loop, HB 21, the Monoceros Nebula, and the Lupus Loop. Our limits are the most stringent to date, yet the large uncertainties in SNR distances and the nature of the progenitor stars do not allow to put severe constraints on ^{26}Al yields from individual supernovae. Based on current nucleosynthesis models, we found lower distance limits which are consistent with other distance estimates for the investigated SNRs.

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